

# OCCURRENCE AND SOURCE OF NATURAL RADIOACTIVITY IN GROUND WATER FROM THE UPPER FLORIDAN AQUIFER IN THE APALACHICOLA EMBAYMENT-GULF TROUGH AREA, GEORGIA

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## INTRODUCTION

The Floridan aquifer system is the most widely used aquifer in the Coastal Plain of Georgia. It is composed of a thick sequence of permeable limestones, ranging in age from Paleocene to early Miocene. Throughout most of its extent in Georgia, the aquifer is confined above by clastic and carbonate rocks, mostly Miocene in age.

The hydrogeology of the Upper Floridan aquifer in southwestern and south-central Georgia is dominated by the presence of a subsurface geologic feature known as the Apalachicola Embayment and by its narrow, northeastward extension, the Gulf Trough (Figure 1.). Within the Gulf Trough and Apalachicola Embayment, both the quality and quantity of water available from the Floridan aquifer system are reduced. Of particular interest is the presence of elevated levels of natural radioactivity in ground water, most contributed by Radium-226. The presence of the radioactivity has necessitated the replacement of several public supply wells.

The purpose of this paper is to define the hydrogeologic controls on the origin and distribution of natural radioactivity in the Gulf Trough/Apalachicola Embayment area. A complex interaction of trough-embayment morphology and facies changes reduces the permeability of limestones of the Floridan system in the study area. The reduced permeability, in turn, produces conditions favorable for the precipitation of uranium-bearing minerals on the aquifer matrix. Decay of these uraniferous minerals releases radium into ground water.

## EXTENT AND ORIGIN OF THE GULF TROUGH- APALACHICOLA EMBAYMENT

The Gulf Trough-Apalachicola Embayment extends, in Georgia, from the extreme southwest corner of the State northeastward to central Bulloch County (Figure 1). The feature is sinuous and trough-shaped, widest at the southwest and narrowing northeastward. The Gulf Trough-Apalachicola Embayment channel system was produced by a marine current, the Suwannee Current, which was active in the study area from the middle Eocene through the early Oligocene (Huddleston, et al. in prep.). This current flowed northeastward from the Gulf of Mexico to the Atlantic, inhibiting sedimenta-

tion in the Apalachicola Embayment and Gulf Trough during the late Eocene. Rising sea level during the late Oligocene and Miocene caused the cessation of the current. Filling of the trough-embayment occurred during the Oligocene and early Miocene.

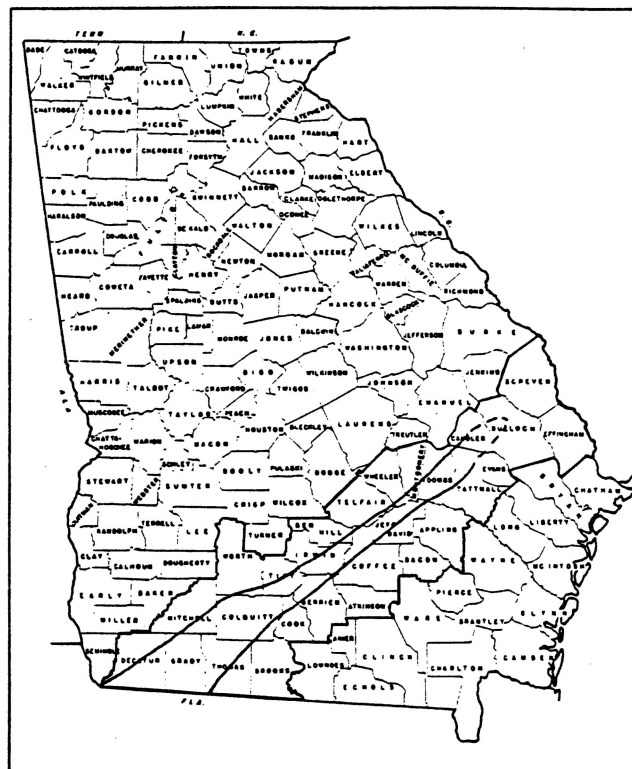


Figure 1. Location and Extent of the Apalachicola Embayment and Gulf Trough in Georgia.

The Suwannee Current controlled sedimentation in the Gulf Trough and Apalachicola Embayment from late Eocene through early Miocene. As a result, the Floridan aquifer system in the trough-embayment changes character. Thick sequences of dense,

### Radioactivity in the Wheeler-Montgomery County Area

relatively impermeable, deep-water limestones replace the more permeable limestones which are present outside the trough-embayment. Overlying the aquifer system in the trough-embayment are thick clastic deposits of Miocene age, also relatively impermeable. These factors combine to reduce the permeability of the aquifer in large portions of the trough-embayment area.

### RADIOACTIVITY OF GROUND WATER IN THE GULF TROUGH-APALACHICOLA EMBAYMENT

Elevated levels of radioactive elements are closely associated with the Gulf Trough-Apalachicola Embayment. Several public-supply wells have yielded water that exceeds drinking water standards for natural radioactivity and have been plugged or reconstructed as a result. In other cases, water from affected and unaffected wells is combined in the municipal water system, and the mixed water then meets drinking water standards.

Radioactivity is a product of the unstable decay of a number of different naturally occurring radioactive isotopes. The Georgia Rules for Safe Drinking Water specify Maximum Contaminant Levels (MCLs) for several specific isotopes as well as for total particle activity. Within the study area, two parameters are known to exceed the MCLs: gross alpha activity and Radium-226. All municipal water systems are tested for gross alpha activity, for which the MCL is 15 picocuries per liter (pCi/l), excluding uranium. Water samples which exceed 5 pCi/l gross alpha activity are then tested for combined activity of Radium-226 and Radium-228 (MCL 5 pCi/l). Laboratory results indicate that Radium-226 is the dominant alpha emitter in the study area and that Radium-228 activity is negligible. Both Radium-226 and 228 are of concern from a health standpoint because they can be ingested and can accumulate in the bones; daughter products of these isotopes are particularly harmful (Gilkeson, et al., 1983).

Radium-226 is a part of the Uranium-238 decay series that follows, in order, Uranium-238, Thorium-234, Protactinium-234, Uranium-234, Thorium-230, and Radium-226. Radium-226 in turn decays to form Radon-222 and a succession of short-lived daughter products. The activity levels of these isotopes vary. Some, like Uranium-238, have low alpha-particle activity, while others, such as Radium-226, are shorter-lived and have high activity levels. Because of the greater availability of data on gross alpha activity, and because the majority of that activity can be attributed to Radium-226, only gross alpha activity was mapped in this study, and it was used to approximate Radium-226 activity.

The two geographic areas that show the highest gross alpha activity are the Tift-Berrien Counties area, and the Wheeler-Montgomery Counties area. The occurrence of radioactivity in these areas follows two separate patterns.

High gross alpha levels in ground water can be associated with high gamma-ray activity resulting from the unstable decay of other radionuclides in the uranium decay series. Gamma-ray logs of water wells can help identify depth intervals within the wells which will produce water with high gross alpha levels.

In the Wheeler-Montgomery Counties area, two distinct depth zones of elevated radiation can be identified on gamma-ray logs. The upper zone appears above the Floridan aquifer in the Miocene section, where it appears to be associated with voids in the limestone (John Fernstrom, EPD, retired, personal communication). The lower zone of high gamma radiation is located at the top of the Floridan aquifer system. Several public supply wells in the area produced water which exceeded drinking water standards for radiation.

The cities of Ailey, Alamo, Mount Vernon, and Tarrytown drilled new wells to replace those that yielded water with high radiation levels. The new wells were cased to greater depths in an attempt to exclude the radioactive zones. Most of these wells subsequently produced water which met standards, with one exception. The replacement well at Alamo was constructed prior to geophysical logging, and was cased to four feet above the base of the gamma-ray anomaly. Water from the well met drinking water standards for five years before the radiation again exceeded standards. In 1987, a third well was drilled and logged, and casing was installed to a depth below the zones of radiation. This well now produces water free from significant amounts of radiation.

### Radioactivity in the Tift-Berrien Counties Area

High radiation levels in ground water from the Tift and Berrien Counties area are restricted to wells that are in or near the Gulf Trough; however not all of the wells within the trough produce radioactive water. Highest levels (20 pCi/l) are found in the vicinity of Tifton, in Tift County, and Alapaha, in Berrien County.

The city of Tifton, on the north flank of the Gulf Trough, has removed municipal well 5 from production due to high radioactivity levels. The gamma log of this well shows large gamma anomalies at depths of 350 feet (cased), 495 feet, and 525 feet. The city replaced this well with municipal well 7, located 3400 feet to the northwest, farther from the trough. The gamma log of well 7 shows moderate gamma-ray activity at 190 feet (cased) and at 290 feet. The gross alpha activity of the water from this well is at or below background levels. Gross alpha activity of water from nearby municipal well number 4 has declined from  $7 \pm 2$  pCi/l to  $4 \pm 1$  pCi/l since well 5 was taken off line.

The city of Alapaha, which lies in the Gulf Trough, has two production wells, both of which produce water with higher than normal amounts of

radioactivity. Gamma-ray logs of these wells show high gamma-ray activity between depths of 380 and 400 feet. A test well (GGS 3555) was drilled, logged, and sampled in an attempt to develop a new well to supply water to the city of Alapaha. An inflatable packer was used to isolate and sample discrete depth intervals. The packer was set at depths of 360, 375, and 381 feet. Tests of water samples collected from beneath the packer for each of these depths indicated gross alpha activities of  $12 \pm 2$ ,  $12 \pm 2$ , and  $10 \pm 2$  pCi/l respectively. A gamma-ray log showed no discrete zones of high radiation. A nearby domestic well, located 800 feet to the east, produces water which meets drinking water standards, but this well is significantly shallower than the city of Alapaha test well. Although at the same land elevation, the domestic well is cased to 272 feet, while the test well is cased to 358 feet.

Assuming that both wells are cased to the top of the aquifer, this means that there is a significant amount of relief on the top of the aquifer. Logs of the city of Tifton municipal wells also indicate that the top of the aquifer is irregular, and wells number 4 and 5, which produce water with higher than normal gross alpha activity, are located in areas where the top of the aquifer is low. Drillers in the Berrien County area also report that high radioactivity seems to be associated with low areas on the top of the aquifer.

#### SOURCE AND CONTROLS OF RADIOACTIVITY IN GROUND WATER IN THE STUDY AREA

##### Sources of Uranium

Uranium-bearing minerals are the ultimate source of the Radium-226 in ground water in the study area. Elevated radioactivity levels are geographically widespread, indicating that the source of the parent isotopes is also widespread. The Miocene and younger sediments in the Coastal Plain contain clastic sediments derived from the crystalline rocks of the Piedmont, which may include radioactive minerals such as monazite. Portions of the Miocene sediments are rich in phosphate minerals, which incorporate uranium in their crystal structure. Under proper conditions the uranium contained in these minerals can be leached and can enter the ground water.

##### Solubility of Uranium

Uranium is soluble under oxidizing conditions, such as those found in waters in recharge areas. Typically, ground water in recharge areas has relatively high levels of uranium, which has a low activity level (Korosy, 1984). As ground water enters reducing conditions, the uranium is deposited on the aquifer matrix, lowering concentrations of uranium in ground water. The uranium then decays, producing daughter products with high activity levels, such as Radium-226, which enter the ground water (Gilkeson, et al., 1983).

Reducing conditions in an aquifer can be

produced where ground-water flow is sluggish, or where reducing agents such as pyrite or organic matter are present in the aquifer. The Gulf Trough and Apalachicola Embayment provide these conditions. The thick sediments overlying the Floridan aquifer system in the Gulf Trough and parts of the Apalachicola Embayment retard the inflow of oxygen-rich water. In addition, the limestones which comprise the Floridan system in the trough and embayment are less permeable and contain more pyrite than their counterparts outside the feature. Finally, the top of the Oligocene section was exposed and eroded. The paleo-karst developed on this surface trapped fine-grained sediments, rich in organic debris.

##### Precipitation of Uranium

High radioactivity levels follow the trend of the Gulf Trough and Apalachicola Embayment, appearing most often in water from the lower Miocene section and the upper portion of the Floridan aquifer system. It is probable that reducing conditions produced in the Lower Miocene sediments and the Oligocene limestones of the Floridan system caused the precipitation of uranium on the aquifer matrix and overlying sediments. The Floridan aquifer system in the Wheeler-Montgomery-Toombs Counties area, though outside the Gulf Trough, is thickly confined and its upper surface karstic and irregular. Therefore it would also provide the reducing conditions necessary for the precipitation of uranium. Radioactive decay of the uranium would then contribute Radium-226 to the ground water.

Gilkeson and others (1984) and Michel and others (1982) demonstrated the importance of analyzing data on all isotopes in the decay series in order to develop a comprehensive model of the distribution of radioactivity in ground water. Thus, further delineation of the controls on the occurrence of Radium-226 will require more data on the distribution of the parent and daughter isotopes. However, the available information is useful in understanding the mechanism by which Radium-226 enters the ground water, and in identifying areas where high levels of natural radioactivity are likely to be encountered.

#### CONCLUSIONS AND RECOMMENDATIONS

High levels of natural radioactivity in ground water from the Floridan aquifer system are associated with the Gulf Trough and Apalachicola Embayment. The highest levels are found in the Wheeler-Montgomery Counties area, and in the Tift-Berrien Counties area.

The ultimate source of radioactivity in the ground water in this area is Uranium-238, probably derived from sources in or near the study area. The crystalline rocks of the Piedmont Province to the north contain such uranium-bearing minerals as monazite, which were weathered and transported into the Coastal Plain. Also, the phosphate minerals of the Miocene sediments overlying the

aquifer incorporate uranium in their crystal structure, and hence are another potential source. Uranium is soluble under oxidizing conditions and precipitates under reducing conditions. Oxidizing conditions in the recharge areas of the aquifer dissolved uranium from these sources and transported it until reducing conditions were encountered. A reducing environment provided by the limestones of the trough-embayment caused the precipitation of uranium-bearing minerals on the aquifer matrix. Reducing conditions in and above the aquifer were produced by a complex interaction of thick overburden, which caused sluggish groundwater flow, and an irregular upper aquifer surface, which trapped organic matter. Once the uranium was deposited on the aquifer matrix, radioactive decay produced Radium-226, which entered the ground water.

Municipalities in the Gulf Trough-Apalachicola Embayment area can reduce the risk of producing radioactive water by siting their wells as far from the center of the trough-embayment as possible and by running gamma-ray logs on newly drilled wells to identify any radioactive zones. By installing casing through these intervals, the production of radioactive water can often be prevented.

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